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Field evaluation of microencapsulated phase change material slurry in ground source heat pump systems

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ABSTRACT

Microencapsulated phase change material (MPCM) slurries were field-tested in ground source heat pump (GSHP) systems in the Southern United States to validate their thermal performance and durability as heat transfer fluids (HTF). MPCM particles consisted of methyl stearate (melting temperature: 39.5 °C) as phase change material (PCM), microencapsulated with polyurea as shell material. Experimental results showed that MPCM slurries transport more thermal energy than water at a constant pumping power due to the higher heat capacity associated with the PCM. Demonstration experiments showed that using MPCM slurries improved the heat load-to-pumping power ratio by up to 34% when using a coaxial heat exchanger. The coefficient of performance of the GSHP system was enhanced by up to 4.9% when using MPCM slurries. It can be concluded that MPCM slurries are viable HTF because of their higher heat capacity. In terms of durability, no significant damage of MPCM was detected under continuous pumping conditions after 123,252 pump-cycles or an estimated life span of 10.5 years. Results also suggest that progressive cavity pumps are more suitable than centrifugal pumps from the durability point of view. Long-term durability studies should be considered for the eventual implementation of MPCM technology in heating and cooling applications.

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1. Introduction

With the development of the human society, energy consumption and environmental pollution have been issues of concerns all over the world. Use of renewable energy sources has gained more attention as possible solutions for energy saving and environmental conservation. Among the various advanced energy systems using renewable energy sources, ground source heat pump (GSHP) systems have become more attractive for the thermal management of commercial and residential buildings because of their high energy efficiency and sustainability [1–3]. GSHP system basically contains a ground loop, where a heat transfer fluid (HTF) passes through it to absorb thermal energy from the surrounding ground. Since the subsurface temperature is not subject to large variations, the GSHP systems can provide nearly constant heating and cooling energy with a high coefficient of performance (COP) [4]. Even though GSHP systems need larger initial investment and maintenance cost, their energy source potential and environmental friendliness are significant enough to make them cost-effective. Several studies have been performed to evaluate the performance of GSHP systems by using various types of ground heat exchangers to enhance the heat transfer performance and reduce the initial investment of such systems [5–10]. However, these systems still require large amounts of HTF to satisfy the heating and cooling demands of buildings. Pumping energy associated with the handling of HTF can be costly, so it is appropriate to consider ways to reduce the volume or pumping cost of HTFs needed for thermal management.

The use of microencapsulated phase change material (MPCM) slurry can be effective in improving the thermal performance of heat transfer systems due to the high heat capacity induced by the phase change material (PCM) when it undergoes phase change. Increased heat transfer performance can reduce the required flow

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rate of HTFs and consequently save energy through decreased pumping power. Many studies have been carried out for a fundamental understanding about the thermal properties, flow and heat transfer characteristics of MPCM slurries. In terms of thermophysical properties of MPCM slurries, adding MPCM particles to any carrier fluid increases its apparent viscosity [11,12]. Apparent viscosity of MPCM slurry at low mass fraction is mainly independent of shear rate, which indicates that MPCM slurry behaves like a Newtonian fluid [12,13]. With respect to the stability of MPCM, microcapsules containing organic PCMs have shown good thermal stability in heating and cooling applications [14–16], even though their thermal physicochemical properties could slightly degrade after several thermal cycles [16,17] due to the partial degradation of microcapsules by breakage [18]. However, small MPCM particles (2–10 μm) can resists continuous pumping conditions without any breakage [19,20] as microscopic observations have revealed, and by measuring and contrasting the thermal properties of used MPCM slurries with fresh samples. Furthermore, increasing the shell thickness of MPCM decreases their breakage of microcapsules [21,22] but it can also lead to lower amount of PCM and lower heat capacity within the HTF [23]. With respect to the pressure drop characteristics of MPCM slurry, mass fraction in the slurry increases pressure drop, which is greater than that of the carrier fluid due to the increased viscosity [23,24]. The friction factor curve of MPCM slurry flowing through a straight tube fits well the correlation used for homogeneous Newtonian fluids [12,20]. Pressure drop of MPCM slurry is lower than that of carrier fluid at certain conditions due to a drag-reducing effect [11,19]. In terms of heat transfer characteristics, MPCM slurry could considerably enhance the heat capacity when compared to water due to the latent heat of fusion of PCM [24,25]. The heat transfer coefficient of MPCM slurry significantly increases during the phase change process [19,20,25,26]. The average heat transfer coefficient of MPCM slurry is typically lower than that of water at a constant fluid velocity condition [20,23,26].

Even though MPCM technology has been studied for the past two decades, MPCM slurries have not been widely implemented in commercial heating and cooling systems including GSHP systems due to the lack of long-term reliable performance data of MPCM slurry. In the present study, MPCM slurry was tested under laboratory conditions to determine the enhancement of the overall performance of a coil heat exchanger (CHX) before deploying MPCM slurry to commercial GSHP systems. In addition, field tests were conducted to evaluate the effect of using MPCM slurries as a HTF on the thermal performance of the GSHP systems on cooling mode, which were located in the Southern United States. The durability of MPCM particles was also examined to determine if they could resist continuous pumping conditions, which is significantly important for the implementation of MPCM slurries in industrial applications.

2. Experimental setup

2.1. Lab-based experimental setup

An experimental setup for the laboratory experiments was built to investigate the benefits of using MPCM slurry in a CHX, before testing the fluids in the field. The CHX used in the lab was the same type of heat exchanger used in the field. A schematic diagram of the experimental setup is shown in Fig. 1. The experimental system mainly consists of two coil heat exchangers (HX01 and HX02), an air-cooled water chiller, a heater tank, pumps (P01 and P02), and a sampling station (SS01). The test section was fully instrumented with a differential pressure transducers (PT01 and PT02), thermocouples (TC01 ~ TC08), and flow meters (FM01 ~ FM03). The hot water from the heater tank was circulated through the annulus of the CHX (HX02) to heat the MPCM slurry until complete melting of PCM was achieved. The cold water pumped by the chiller was circulated through the annulus of the CHX (HX01) to cool the MPCM slurry until the phase change material crystallized. The MPCM slurry delivered by the centrifugal pump (P01) was circulated through the inner tube of both heat exchangers. Pressure drop and heat transfer rate of MPCM slurry were determined using the first CHX (HX01). For comparison purposes, experiments using water were performed under the same flow rate and temperature conditions as with the MPCM slurry.

2.2. Field-based experimental setup

A ground source heat pump (GSHP) system installed in Texas, United States was selected for field testing, which is used mainly for cooling purposes. The GSHP system includes 108 wells of 25.4 mm bore holes with a depth of 91.4 m. Water is circulated from the

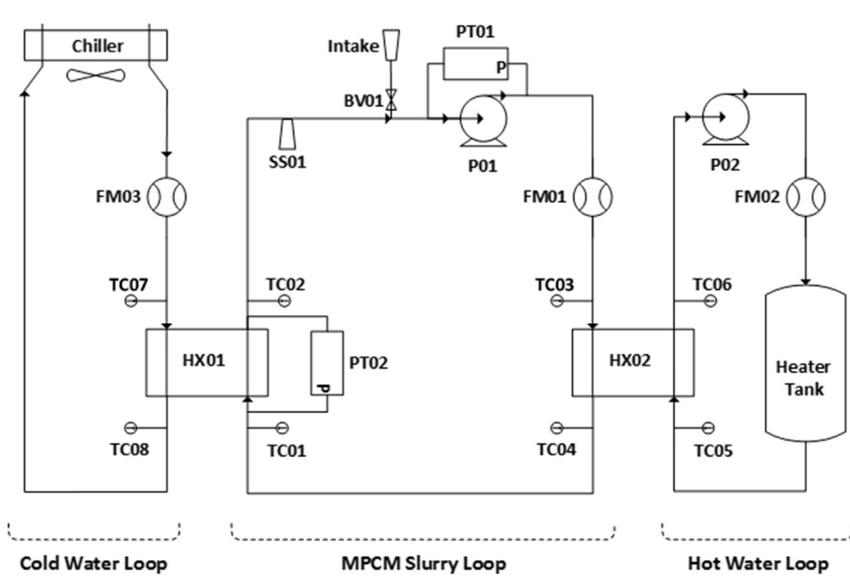

Fig. 1. Schematic diagram of experimental setup.

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